THE EFFICIENCY OF REFLECTORS WITH THE USE OF THE GLOBE PHOTOMETER

BY

JAMES W. COHN
CHARLES H. SWARTZ

ARMOUR INST. OF TECHNOLOGY
1914

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"THE EFFICIENCY OF REFLECTORS WITH THE USE OF THE GLOBE PHOTOMETER."

A THESIS

PRESENTED BY

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INTRODUCTION

The sources of error in light measurements are many, and in some cases unavoidable, on account of its dependence upon the eye of the observer. This paper is the record of an attempt at the accurate measurement of the efficiencies of reflectors with the use of "The Globe Photometer." All measurements were taken in sets of eight, by two observers, who made their observations independently. A record of the original data is given on the data sheets.

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.ABBREVIATION SHEET

I	CURRENT.
E	VOLTS.
D	DIRECT READING OF BECKSTEIN PHOTOMETER.
R	REVERSE READING OF BECKSTEIN PHOTOMETER.
L	LENGTH IN CM. FROM BOTTOM OF GLOBE.
V	VOLTMETER.
A	AMMETER.
R	IN SCHEMES . . . RESISTANCE.
B	IN SCHEMES . . . BATTERY.
A-B-C-D-	LAMPS USED ON DATA SHEETS.
S	MILLIVOLTMETER READING WITH 1.604 SETTING ON SHARP-MILLAR PHOTOMETER, & REFLECTOR IN POSITION.
T	SHARP-MILLAR PHOTOMETER READING WITH AVERAGE MILLIVOLTMETER SETTING AS FOUND IN "S".
U	MILLIVOLTMETER SETTING EQUAL 98.3 AS FOUND WITHOUT REFLECTOR . . . SHARP-MILLAR PHOTOMETER READINGS.
C.P.	CANDLE POWER.
CM.	CENTEMETER.
M.V.	MILLIVOLTMETER.
AV.	AVERAGE.
S.M.P.	SHARP-MILLAR PHOTOMETER.
EFF.	EFFICIENCY.
R-6-D	READ AS REFLECTOR 6 WITH LAMP D, ETC.
M.S.C.P.	MEAN SPHERICAL CANDLE POWER.
M.H.C.P.	MEAN HORIZONTAL CANDLE POWER.
M.H.S.C.P.	MEAN HORIZONTAL SPHERICAL CANDLE POWER.

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OUTLINE

"THE EFFICIENCY OF REFLECTORS WITH THE USE OF THE GLOBE PHOTOMETER."

1. Introduction.
2. Description of Apparatus.
    - (a) The Beckstein Photometer.
    - (b) The Sharp-Millar Portable Photometer.
    - (c) The Ulbrich Globe.
    - (d) Scheme of Connections for Apparatus.
3. Procedure and Methods of Reducing Errors.
    - (a) Outline of Procedure.
    - (b) Measurement of M.S.C.P. of Test Lamp.
    - (c) Losses and Their Elimination.
4. Description of Reflectors and Their Efficiencies.
5. Possible Uses of Measurements by Globe Photometer.
    - (a) M.S. and M.H.S.C.P. of Incandescent and Arc Lamps.
    - (b) Mechanical Equivalent of Light and Input, Output, Efficiency of Incandescent Lamps.
    - (c) Absorption Due to Different Colored Paints and Calcimines.
6. Conclusion.

DESCRIPTION OF APPARATUS.

BECKSTEIN PHOTOMETER: The Beckstein Photometer consists of a plaster-paris disk, both sides of which are viewed through the eye piece. In the path of the rays between the disk and the eye piece are inverted two biprisms. A balance is obtained when the light falling on both sides of the disk are equal. The biprisms are so arrange that a balance may be obtained when the quadrants or semi-circles are in contrast or equality. There is a device connected with the photometer by which the disk is reversed so that the side facing the right hand source will face the left hand source. In measurements made, the equality of brightness was used.

THE SHARP-MILLAR PHOTOMETER.

SHARP-MILLAR PHOTOMETER: The form of portable photometer most generally used in this country is the "SHARP-MILLAR. This instrument is

comprised of one piece of apparatus, which has the following features:- portability, simple means of operation, and the best means of obtaining a sensitive balance. The construction of the photometer is shown in the accompaning figure.

At one end of the photometer box "A" is a "Lummer-Brodhun"prism set, which is observed through an eye piece located on the side of the box. To obtain a balance, the distance between the comparison lamp "B" and the screen is varied. The comparison lamp, which has a tungsten filament, receives its power from the storage battery.

Referring to the figure, the knob "C" is seen, and when turning same, moves the comparison lamp back and forth by means of small grooved wheels running on tracks. At "D" is located a milk glass plate upon which falls the light from the comparison

lamp received from the eye piece. From the law of inverse squares, the intensity of light varies inversely as the square of the distance from the comparison lamp. The above is done by means of screens, which are moved with the comparison lamp, and at the same time intercept all other light than that from the comparison source.

On the upper part of the front side is a scale made of translucent material, graduated with the inverse square scale. The comparison lamp throws light on the scale by means of a shutter and small slit, which allows readings to be taken in dark places, and also determines the position of the lamp at any instant. At one end there are two terminals for the source of supply, and two for a voltmeter.

One of the most important parts of the photometer is the elbow tube which fits tight into a collar at one end of the box. This elbow can be turned at any angle, which is indicated on a scale at the end of the box. The elbow tube contains a reversible plate used to measure either candle power or illumination in any direction. The side of the tube used for measuring candle power has a diffusely reflecting surface, while the other side is a mirror used for illumination. In both cases, the test plates on the end of the tube is used to take readings. For intense illumination an absorbing plate is required between the elbow tube and prism, this equalizing the two fields to bring the point of balance within the desired limits. By means of these glasses, a range of .004 Ft. and 2000 Ft. candles is obtained.

ULBRICH GLOBE PHOTOMETER: The need for suitable appliances for the determination of M.S.C.P. or the total luminous flux from a source of light has made itself felt in recent years.

Early experimentors used the point by point method; that is, the measurement of candle power in a large number of directions distributed uniformly over the surface of an imaginary sphere surrounding the lamp. Several forms of integrating devices, such as, Mathew's Photometer, have been developed at different times, but, none have been as simple in construction, or as satisfactory in operation as the Globe Photometer.

The Globe Photometer consists of a sphere 120 cm. in diameter, the frame of which is made up of two hemispheres lined with a coating of asbestos which is cut into

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segments so that they fit into place. The asbestos is .1578 cm. in thickness.

The hemispheres are secured by metal clamps. The interior of the globe is coated with white calcimine. There is an opening in the upper portion of 46.356 cm. in diameter to insert lamps, and one at the side of the same diameter used to repair the inner surface.

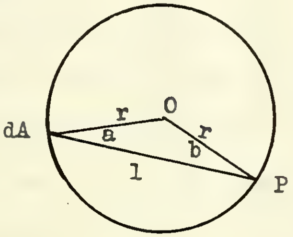
There is an observation window covered with diffusing glass a little below the central horizontal position, upon the luminosity of which the measurements depend. A screen is used to prevent direct rays of the lamp from falling upon the observation window. The translucent screen has the property of uniform transmission of light of all wave lengths throughout the visible spectrum.

The features that should be considered in

coating the inside of the globe are; nearest approach to perfect diffusion; absence of selective absorption; and permanency of surface.

The illumination of the inner surface is made up of two parts, one a variable, the direct rays from the lamp, and the other a constant resulting from the multiple diffuse reflection of light. The latter is directly proportional to the total flux emitted by the lamp. A window of milk glass located in one side of the sphere is screened from the direct rays of light and is illuminated only by the uniform reflected component, and its brightness is, therefore, proportional to the total flux from the lamp . A photometric observation of the window may be taken from without and the M.S.C.P. found by multiplying the apparent intensity of the window by a previously

determined constant. It remains to be proven that the light reflected from any element dA of the interior surface falls with uniform density on all other portions of the surface.



The sphere is represented by a section, passing through dA; a point perpendicular, whose illumination is to be considered; and the center of the sphere, O. The boundary of this section is a great circle of the sphere. Assume that the light reflected by dA obeys the law of inverse squares, and the cosine law of diffusion.

Let I equal normal intensity of dA, and dE the illumination perpendicular from dA. Considering the first reflection only, we get

$$dE_1 = \frac{I_A \cos a \cos b}{l^2}$$

from definition and cosine law.

The light received from dA directly from the lamp equals EdA equals F, the total light emitted by the lamp.

The intensity or luminosity of dA is equal to KEa, where K is the coefficient of diffuse reflection. Angle a equals angle b, the normals being radii of the same circle and the angles are base angles of an isosceles triangle. The light received from dA at P, once reflected is equal to F_A

$$F_A = \frac{kI_A \, dA \cos a^2}{l^2}$$

$$l = 2r \cos a, \quad l^2 = 4r^2 \cos^2 a$$

$$F = E_A \, dA = \frac{kI_A \, dA \cos^2 a}{l^2} = \frac{kI_a \, dA}{4r^2}$$

$$I_A \, dA = E_A \text{ (by definition)}$$

$$\frac{kr}{4\pi} \text{ summation } E_A \, dA = \frac{k}{4r^2} F$$

Illumination at P for light twice reflected equals $(\frac{k}{4r})^2$ F, for light three times reflected $(\frac{k}{4r})^3$ F, and so on for any number of times. Hence, the illumination at P, for light reflected any number of times equals KF, where K is the constant of the instrument.

In measuring by diffusion methods, a definite fraction of a total flux is allowed to fall upon a screen of small area. The total flux is evaluated in terms of the resulting luminosity of the screen, measured by simple photometric means.

It has been found that the constant varies slightly with the distances that the lamp is placed from the bottom or the top of the globe. The probable cause of the variation

of the constant is the error caused by the screen between the source of light and the observation window. A different error will be introduced for different positions of the lamp, for in some positions more direct rays will strike the screen than in others. For some positions of the lamp the screen will interfere with the reflected flux of light from the part of the lamp where the intensity is a maximum, while in another position, it will interfere with the flux from a less intense part. This will cause a variation in the number of times the light is reflected, for different positions, which will cause a difference in illumination on the observation window, due to the absorption of the diffusing surface. The effect of the screen will vary with the distribution of the flux of light and probably with the color of the light.

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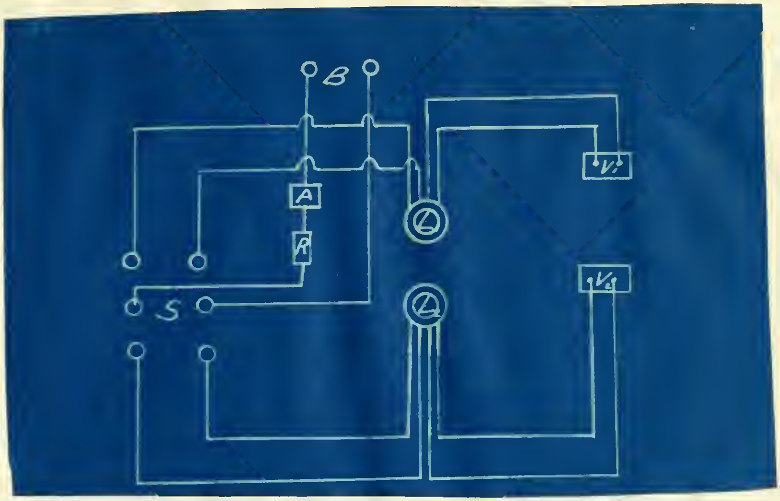
The above effect, due to the screen may be eliminated by the use of a partially translucent screen. The degree of translucency must be found by experiment such that the light which the screen transmits to the window exactly compensated for the loss caused in other ways.

To eliminate the error due to the absorption of the bulb or globe of the lamp to be tested, the sphere may be calibrated by an incandescent electric lamp standard, after the lamp to be tested is placed in the position which it will occupy during the test.

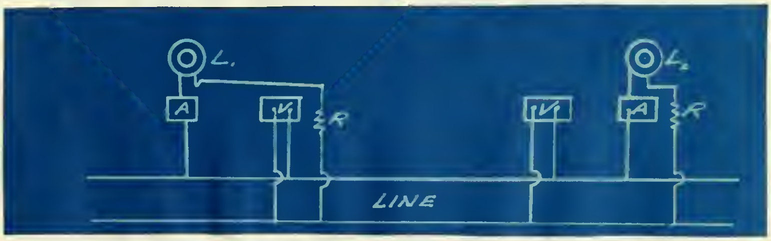
In using integrating spheres, the substitution method of photometry must be depended upon. If lamps of a different characteristic are to be measured using the same constant, the design and screening

become important items. The integrating spheres may be used in conjunction with the existing photometric apparatus.

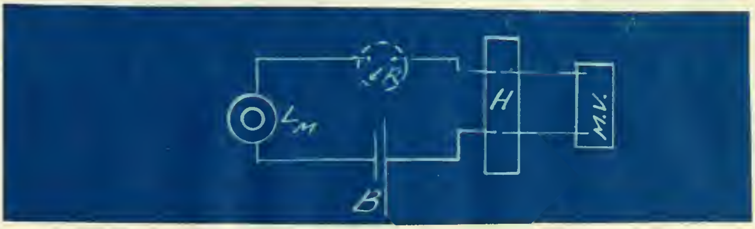
The above arrangement may be used and a photometric balance obtained by moving the comparison lamp. A convenient type of portable photometer may be used. With the portable type, the globe is calibrated, as follows: The M. S. C. P. of a lamp is determined by some suitable means. This lamp is placed within the Globe and the portable photometer set at the window and made to read (by varying the current through the test lamp of the portable photometer), the M.S.C.P. of the lamp. Hence, when another lamp is placed within the Globe, the portable photometer will ready directly in M.S.C.P., because, the light falling on the window is directly proportional to the M.S.C.P. of the lamp, as shown in the preceeding theory.



SCHEME OF CONNECTIONS FOR GLOBE



SCHEME OF CONNECTIONS FOR BENCH



SCHEME OF CONNECTIONS FOR SHARP-MILLAR

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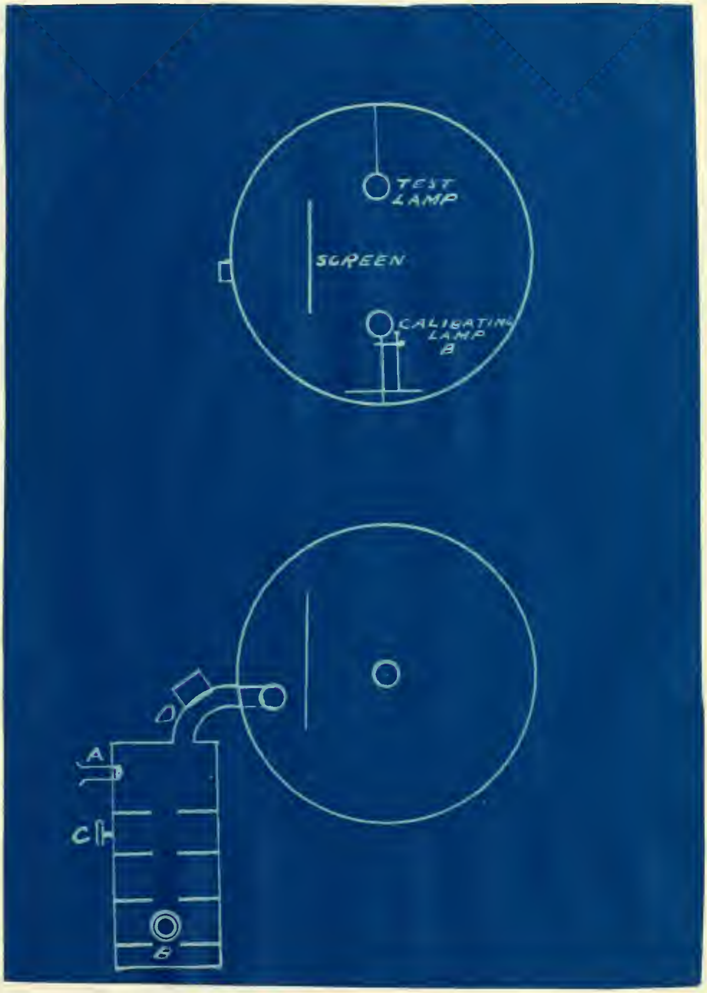

ARRANGEMENT OF SHARP-MILLAR AND GLOBE PHOTOMETER.

PROCEDURE AND METHODS OF REDUCING ERRORS

OUTLINE OF PROCEDURE: The method of procedure may be outlined, as follows; The M.S.C.P of an incandescent lamp is found by one of the known methods, and the lamp is suspended in the globe: The SHARP-MILLAR PHOTOMETER is placed to read the illumination on the observation window of the globe, and the screen is set to read some multiple or fraction of the M.S.C.P. of the lamp whose M.S.C.P. has been determined: The current through the lamp in the SHARP-MILLAR is then varied until a balance is obtained, and the reading on the millivoltmeter is observed, hence, when another light source replaces the test lamp and the reading on the millivoltmeter is the same as observed above, the SHARP-MILLAR will read the M.S.C.P. of the light source, when a balance is obtained; The M.S.C.P. is obtained without the reflector and then with it, the difference representing the loss due to the reflector, and the percent efficiency of the

reflector will be represented by the M.S.C.P. with the reflector to the M.S.C.P. without the reflector times 100. The above would be the general procedure for finding the efficiency of any light unit. In finding the efficiency of opaque reflectors, charging a loss of light flux due to the absorption of the outside of the reflector, would not be just to the reflector under test. In practice, when opaque reflectors, such as enameled steel, are used, all the light flux is directed downward and only an unappreciable amount reaches the outside of the reflector, while in the globe, due to the high diffusion coefficient of the interior, a large amount would fall upon the exterior of the reflector. hence, if the general method were used, the efficiency at operating conditions would not be obtained, therefore, another

method was used, which will be described later.

MEASUREMENT OF THE M.S.C.P. OF TEST LAMP: The M.S.C.P. of the lest lamp was measured by determining the mean horizontal candle power of the test lamp, and multiplying it by the spherical reduction factor of the type of lamp used. The M.H.C.P. was found by comparing the horizontal candle power for twelve positions in the horizontal plane 30 degrees apart, of test lamp "A" running at 110 volts and taking .88 amperes, against the candle power of the tungsten standard No.4573, standarized by the Bureau of Standards at Washington, to give 80 candle power in given direction when operating at 106.9 volts and taking .891 amperes. The comparison was made with a Beckstein Photometer, using the equality screen.

Eight readings on the photometer bar were taken for each position or station, four by each observer. Each observer took two readings with the screen in the direct position, and two with the screen in the reverse position, so as to eliminate the error due to the difference in absorption and diffusion of both sides of the disk.

The average of the readings by each observer was taken and the average of these averages taken for each position. The candle power for the twelve positions were then found by means of the relation at the candle power varies directly as a square of the distance from the lamp to the disk.

The average candle power or the M.H.C.P. of the lamp under test was found to be 89.55 Candle Power, hence, the M.S.C.P. will be 89.55 times .79 equals 70.5. The above procedure was repeated with a tungsten lamp rated at

250 watts when operating at 110 volts. The lamp was found to take an average current of 2.25 amperes, and have a M.H.C.P. of 203.1. Hence, the lamp has a M.S. C.P. 203.1 times .79 equals 160.4. The readings for lamp "A" are shown on data sheet No.1.

LOSSES AND THEIR ELIMINATION: The next step in the procedure is to find the constant of the globe, that is, to find the setting on the millivoltmeter, or, the current through the lamp, in the Sharp-Millar Photometer, that will enable us to read the M.S.C.P. or a multiple or fraction of the M.S.C.P. of any unit placed in the globe when a photometric balance is obtained. Lamp "A" was suspended in the globe and the Sharp-Millar was set to read 7.05, which is .1 times the M.S.C.P. of lamp "A". By means of a rheostat in series with the test lamp in the Sharp-Millar, the current through the lamp

was varied until a photometric balance was obtained. The reading on the millivoltmeter will be the one to use if the M.S.C.P. of another light source is to be found.

According to the theory of the globe, the flux falling on the observation window will be proportional to the M.S.C.P. of the unit within the globe, that is, the M.S.C.P. of light unit is equal to k F, and is equal to large K times the illumination on the observation window. With the proper value of current through the test lamp in the Sharp-Millar, as found above, K is made equal to one (1), and since the Sharp-Millar reads illumination directly, it now reads M.S.C.P. directly, when a photometric balance is obtained.

Previous observers have found that a variation in the distance of the lamp from

the top or bottom of the globe would cause a slight variation in the constant, hence, a variation in the millivoltmeter reading would be required. The present observers found the variation in the millivoltmeter reading for different positions of the lamp in the globe, varying the height from 10 cm. from bottom to 90 cm. from bottom. The readings obtained are noted on data sheet No. 2. The same procedure was followed with the 250 watt lamp, which will be referred to as lamp "B", and the readings obtained are noted on data sheet No. 3. It may be noticed that the variation does not vary in any regular manner, and that the greatest variation in lamp "A" from 40 cm. to 90 cm. from bottom is .4 of one division in 109.2 division, or, .366 of one percent (1%). This variation may be considered negligible.

Hence, the constant may be considered not to vary between the distances of 40 and 90 cm. from the bottom, which is the limits within which the units are usually placed.

In order to determine if there is any appreciable error due to the leakage of light from the globe, the observers determined the millivoltmeter reading with lamp "B" 60 cm. from the bottom, with the side door open, the top off, and both the door open and top off. The readings may be seen on data sheet No. 3.

In order to check our method, we determined the M.S.C.P. of "B", using "A" as a standard, and "A" using "B" as a standard. We found that the values check those found by using the bench and the Beckstein Photometer, within two percent (2%).

To find the efficiency of opaque reflectors, the method used is slightly different from the general method, because, it would not be fair to charge to the reflector the loss due to the absorption by the dark colored outside surface.

The calibrating lamp "B" whose M.S.C.P. is known was mounted on a rod 30 cm. from the bottom of the globe. Everything placed within the globe, except the lamps, was calcimined white so as to approximate more nearly, constant diffusion upon which the theory of the globe depends. The lamp "B" was connected to the source through an ammeter and carbon plate rheostat, and to one side of a double pole double throw switch, as shown in the scheme. Lamp "B" was used as the calibrating lamp and remained in the globe through all measurements.

In order that the efficiency of each reflector may be found with different size lamps, it becomes necessary to find the M.S.C.P. of three lamps, "A", "C", and "D". Lamp "A" is a 100 watt tungsten filament lamp, previously used as a calibration lamp. Lamp "C" is a 250 watt tungsten filament lamp, taking 2.28 amperes, at 110 volts. Lamp "D" is a 150 watt tungsten filament lamp, taking 1.25 amperes, at 110 volts.

The lamp whose M.S.C.P. we wanted to determine was placed in the globe 60 cm. from the bottom. This lamp was connected to the source through an ammeter and rheostat, to the opposite side of the double throw switch, to that which lamp "B" was connected, as shown in the scheme. Voltmeter leads were connected from each socket to voltmeters.

To illustrate the method used, we will go through the procedure of finding the M.S.C.P. of lamp "C". We placed lamp "C" in the upper position in the globe, and allowed lamp "B" to operate by closing its circuit through the switch. We then set the SHARP-MILLAR PHOTOMETER to read 1.604. The current through the test lamp in the SHARP-MILLAR was then varied until a balance was obtained. These readings are noted in the first column of data sheet No. 4, the average of which was found to be 98.3 divisions on the millivoltmeter. The switch was then placed to close the circuit of lamp "C", and with a setting of 98.3 on the millivoltmeter a photometric balance on the SHARP-MILLAR PHOTOMETER was obtained. The reading on the SHARP-MILLAR PHOTOMETER, multiplied by 100

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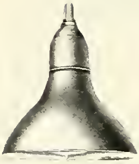
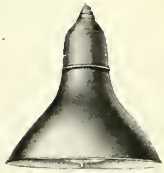
will be the M.S.C.P. of lamp "C". The readings are shown in column 2 of data sheet No. 4. The average M. S. C.P. was found to be 159.3. The same procedure was followed with lamps "D" and "A" which were found to have M. S. C.P.'s of 85.1, and 70.9 respectively. The M.S.C.P. of lamp "A" as found on the bench was 70.5, but, since we are primarily interested in the efficiency of reflectors, we will use 70.9, the M. S.C.P. of "A" as found by the globe.

In all readings involving the lamps and the globe, special care was taken that the voltage was at its proper value and that all direct rays from the lamps within the globe were screened from the observation window. The latter precaution is necessary in order to conform with the theory of the globe.

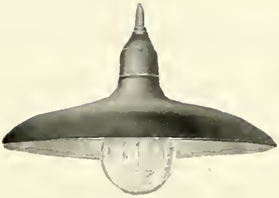
In making measurements some interesting data concerning the lamps were obtained. Data sheet No. 8 shows the current, voltage, rating, watts input, M.H.C.P., M.S.C.P., watts per M.S.C.P. and lumens per watt, for each lamp.



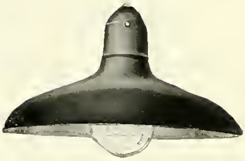
R-2



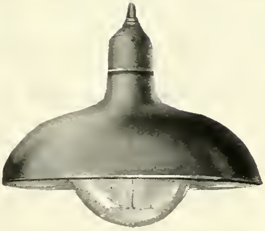
R-3



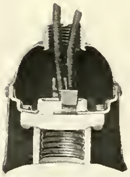
R-6



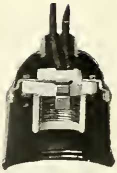
R-4



R-5



LOW POSITION



HIGH POSITION

DESCRIPTION OF REFLECTORS AND THEIR EFFICIENCIES.

To secure efficient illumination for all purposes, it is necessary to use reflectors which have the best reflecting and diffusing characteristics. The reflectors used in this work will be designated as, R-2, R-3, R-4, R-5, R-6, R-7, R-8, R-9 and R-10. The first five of these reflectors were obtained on consignment from the Electric Service Supplies Company. Reflectors R-7, R-8, R-9 and R-10, were taken from the various rooms of Armour Institute of Technology.

Reflectors R-2, R-3, R-4, R-5 and R-6, are made of steel and finished in porcelain enamel. The outer surfaces or tops of reflectors are of dark blue finish, while the inside surfaces are coated with white enamel. Reflectors R-2, R-3 and R-5 are known as the bowl type. Their respective diameters are 8 inches, 9 inches and 16 inches. The height

of R-2 is 8-1/2 inches; of R-3, 9-1/2 inches; of R-5, 11 inches. The wattage of lamps used in R-2 and R-3 are from 60 to 150 watts, while those in R-5 vary from 100 to 400 watts. Reflectors R-4 and R-5 are known as the dome type. The diameter of R-4 is 14 inches and the diameter of R-6 is 18 inches. Lamps ranging from 60 to 250 watts are used in this 14 inch dome type. In R-6,lamps from 100 to 250 watts are the best suitable for this type. The diameters of R-4 and R-6 are 14 inches and 18 inches respectively, while their heights are 8 and 8-1/2 inches respectively.

An interesting factor concerning these steel reflectors is the positioning device shown in figures 1 and 2. Receptacle in low or "1" position is known as the extensive illumination position, while the

position of receptacle in the high or "2" position is called intensive illumination. This adjustment is obtained by simply reversing the positioning device by means of two small screws on each side. A complete reflector consists of a designed steel reflector and the universal holder socket. The advantage of this holder socket is that the reflector can be conveniently removed for cleaning purpose whenever desired, without touching a screw or disconnecting a wire. This universal socket eliminates all separable devices and undesirable methods of attaching reflectors to sockets. The holder socket allows the user to interchange the dome or bowl type without changing the socket.

Reflector R-7 is known as the Holophane opal glass ball. This ball type is intended for

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general illumination rather than for concentrating the light in any given direction. The diameter of the one used is 21 cm., while the opening in the top is 15 cm. In this opal ball the diffusing properties are excellent and efficiency high. The best lamps used in this type are the 100 and 150 watt, because, too much heat is given off from the lamps rated over 150 watts. They are especially well adapted for chandelier work where it is desired to light a large area.

Reflector R-8 is a reflector made of white glass free from spots and blotches. This reflector is known as the small Sudan. It does not reflect so large a percentage of light beneath as the steel reflectors, but, allows a large quantity to pass upward through it. This type of reflector gives perfect diffusion and the reflected light

is free from glare. The reflector has a smooth interior, upon which dust does not readily collect, and from which it is easily removed.

The percentage of transmitted light is greater in the Sudan Reflector, than in the Opalux type, making them particularly adaptable to conditions of higher values of ceiling illumination. The reflecting surface is depolished; there is no glare, and the effect of the transmitted and diffused light is restful to the eyes. Reflectors made of such material as the Sudan appear as a soft luminous mass, where a similar share of the glass shows an outline with a bright spot in the center. This type of reflector is best recommended for ceilings which are low and ornamental, and where it is

necessary to put the light only slightly above the range of vision.

Reflector R-10 is identically the same type as Reflector R-8, but, is called the large Sudan. The size of Reflector R-8 is 27 cm. in diameter, and 13 cm. deep, while Reflector R-10 is 26 cm. in diameter, and 17 cm. deep. The best types of lamps used in Reflector R-9, are the 150 and 250 watt. In the large Sudan, the same size lamps as Reflector R-8 is best adapted. These two reflectors were obtained from the lecture rooms at Armour Institute of Technology.

The reflector known as R-9 is called the Holophane Intensive Type Reflector. From the name intensive it can be seen that this type is used in large rooms with moderate height and for work benches where a strong concentrating distribution is required. The reflector is made of crystal

glass with a smooth interior, but, rather an irregular exterior. The size of this reflector is 27 cm. in diameter and 26 cm. deep. The sizes of lamps used in this type of reflector are 150 and 250 watt. The losses and efficiencies of these reflectors with different lamps are given on the data sheets.

The efficiency of a reflector, with a given lamp is the ratio of the M.S.C.P. of that lamp with the reflector to the M. S.C.P. of the lamp without the reflector. The efficiency of reflector No. 6 with lamp "C", indicated as R-6-C was found as follows: Lamp "C" with reflector No. 6 was placed in the upper position in the globe; Lamp "B" was made to operate at 110 volts; The SHARP-MILLAR PHOTOMETER was set to read 1.604; The current through the test lamp of the SHARP-MILLAR PHOTOMETER was varied until a balance was obtained, and the setting on the millivoltmeter was observed; The average setting was found to be 96.0; The Circuit through test lamp "B" was broken and lamp "C" was made to operate; with a setting of 96.0 on the millivoltmeter, a photometric balance with the SHARP-MILLAR PHOTOMETER was obtained; The SHARP-MILLAR PHOTOMETER reading multiplied by 10 will be

the M. S.C.P. of R-6-C, the average of which was found to be 142.2; The efficiency is equal to the M.S.CP. with reflector to the M.S.C.P. without the reflector equals $\frac{142.2}{159.3}$ equals .890 equals 89.0 percent. Lamp "C" was replaced by "D" and with the setting of 96.0, the procedure was repeated, and the efficiency of R-6-D was found to be 88.0 per cent. The procedure was repeated with lamp "A", the efficiency of which was found to be 81.6 percent. Efficiencies of R-6, R-5, R-4, R-3, and R-2 were found with lamps "C", "A" and "D". A new millivoltmeter setting was obtained for each reflector. The data are shown on data sheets No. 5, 6 and 7.

The efficiencies of R-7, R-8, R-9 and R-10, which are glass reflectors, were found by the ratio of the M. S. C.P. of lamp and reflector to the M.S.C.P. of lamp without

the reflector , using the same millivoltmeter setting that was used when the M.S.C.P. of the lamp was determined. To determine the efficiency of R-10-D; the millivoltmeter setting was 98.3; the average M.S.C.P. is 64.4; hence, the efficiency is, $\frac{64.4}{85.1}$ equals .757 equals 75.7 percent. The data obtained, using glass reflectors, may be found on data sheet No.7.

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POSSIBLE USES OF MEASUREMENTS BY GLOBE PHOTOMETER.

M. S. and M.H.S.C.P. of INCANDESCENT AND ARC LAMPS; The GLOBE PHOTOMETER may be used to determine the M.S.C.P. and the M.H.S.C.P. of light sources. The total flux may be determined by one setting with an accuracy within 2 percent error. The determination of the M.S.C.P. of Arc Lamps by the ordinary methods is difficult, due to its inconsistency. When the "GLOBE" is used the M.S.C.P. of the lamp at any instant may be found, hence, a fairly accurate mean value may be found.

MECHANICAL EQUIVALENT OF LIGHT AND INPUT, OUTPUT, EFFICIENCY OF INCANDESCENT LAMPS; The Mechanical Equivalent of Light so namedby the observers, on account of its analogy with the mechanical equivalent of heat may be determined for any type of lamp, with the aid of the

GLOBE PHOTOMETER. The mechanical equivalent of light may be defined as the work required to produce unit flux. When ergs lumens are used as units, it may be defined as the ergs of work required to produce one lumen. When the mechanical equivalent of a particular type of light source is known, all that is required to determine the input, output efficiency of any lamp in that type, is to know the input to the lamp and its M.S.C.P. The mechanical equivalent is not constant for all types of light sources, due to its variation with the color of light emitted.

ABSORPTION DUE TO DIFFERENT COLORED PAINTS AND CALCIMINES; It is possible, by means of the GLOBE PHOTOMETER, to determine the absorption of light flux per square foot of area, due to the different colors and grades of paint and calcimine, using the absorption due to white paint or clacimine as a standard.

CONCLUSION

The fact that the efficiency of reflectors may be determined with the use of the GLOBE PHOTOMETER will increase its importance as a photometric instrument, which may lead to new methods of light measurements.

DETERMINATION OF M.H.C.P. OF LAMP "A"

Sta.No.	1	2	3	4	5	6	7	8	9	10	11	12
D	127.8	128.5	127.4	126.1	127.9	125.4	126.2	126.7	127.4	128.4	126.7	126.4
	128.0	128.5	127.8	126.0	127.4	125.5	126.1	126.9	127.5	128.2	127.1	127.5
R	130.8	131.1	130.2	129.3	131.2	129.5	129.4	130.2	130.2	128.3	131.3	130.1
	131.0	132.0	130.9	130.0	130.6	129.3	129.1	130.3	130.9	131.4	130.5	129.5
Av.	129.4	130.0	129.0	127.8	129.2	127.4	127.7	128.5	129.0	129.0	128.9	128.1
R	130.9	131.8	131.0	129.6	131.0	129.6	129.2	130.1	130.7	131.2	130.2	129.7
	131.4	131.9	130.9	129.6	130.3	129.5	129.5	130.1	130.8	131.9	130.2	130.0
D	128.4	128.9	128.0	126.7	128.6	127.1	125.8	126.9	127.3	128.5	127.2	126.0
	126.4	128.1	127.0	125.8	126.8	125.9	125.8	126.9	127.5	127.8	126.8	126.8
Av.	129.2	130.1	129.2	127.9	129.1	128.0	127.5	128.5	129.0	129.8	128.6	128.1
Av. of Av.	129.3	130.0	129.1	127.8	129.2	127.7	127.6	128.5	129.0	129.4	128.7	128.1
C.P.	91.2	93.0	91.0	86.8	91.0	86.7	86.5	89.3	90.8	91.4	89.5	89.2

GRAND AVERAGE M.H.C.P. = 89.55

DISTANCE BETWEEN TEST LAMP "A" AND STANDARD EQUALS 250.4 CM.

DATA SHEET NO.1

"LAMP A"

VARIATION OF CONSTANT WITH DISTANCE OF LIGHT UNIT FROM BOTTOM OF GLOBE.

L.	10	20	30	40	50	60	70	80	90
	110.0	-	108.5	109.8	109.5	109.8	109.9	109.9	109.6
	110.0	-	108.2	109.3	110.0	109.6	109.2	109.5	109.7
	110.2	-	109.1	109.1	108.9	109.2	109.5	110.0	110.0
	109.9	-	108.1	109.1	109.4	109.8	109.6	109.5	110.0
Av.	110.1	-	108.4	109.5	109.4	109.4	109.5	109.6	109.8
	110.1	-	108.0	108.9	109.1	109.2	109.2	109.2	110.0
	109.9	-	108.4	109.8	109.1	109.5	109.0	109.3	110.2
	109.9	-	108.4	109.9	109.0	109.0	109.7	109.9	109.2
	110.8	-	108.1	109.0	109.4	109.0	108.7	109.2	109.9
Av.	110.0	-	108.3	109.4	109.3	109.3	109.2	109.5	109.8
Av. of Av.	110.0	-	108.3	109.4	109.3	109.3	109.2	109.5	109.8

ALL MEASUREMENTS MADE FROM CENTER OF FILAMENT.

SCREEN PLATE PLACED 15 CM. FROM CENTER OF FILAMENT.

M.S.C.P. OF TEST LAMP "A" = 89.33 x .79 = 70.57

DATA SHEET NO. 2

LAMP"B"

VARIATION OF CONSTANT WITH DISTANCE OF LIGHT UNIT FROM BOTTOM OF GLOBE.

L.	30	40	50	60	70	80	DOOR OPEN 50	DOOR OPEN 60	TOP OFF 60	TOP OFF DOOR OPEN 60
	107.0	107.8	108.3	108.2	108.5	109.0	107.3	107.0	107.0	106.9
	106.9	107.2	108.0	107.9	108.9	109.2	107.1	107.8	108.0	107.0
	107.4	108.0	108.1	108.0	109.1	109.9	107.1	107.2	108.0	107.2
	107.1	107.6	108.1	108.2	109.1	109.0	107.0	107.9	108.0	107.0
Av.	107.1	107.6	108.1	108.1	108.9	107.4	107.1	107.4	107.7	107.0
	107.0	107.7	108.0	108.0	108.5	109.0	106.5	107.0	107.5	107.0
	107.2	107.8	108.1	108.2	108.9	109.2	107.0	108.0	107.9	107.0
	107.0	107.9	108.0	108.2	108.4	109.2	107.0	107.2	108.0	107.0
	107.2	107.9	108.0	108.8	109.0	109.1	106.8	107.0	108.0	109.0
Av.	107.1	107.8	108.0	108.3	107.7	109.1	106.8	107.0	107.8	107.0
Av. of Av.	107.1	107.7	108.0	108.2	108.3	108.1	106.9	107.2	107.7	107.0

ALL MEASUREMENTS MADE FROM CENTER OF FILAMENT.

SCREEN PLATE PLACED 15 CM. FROM CENTER OF FILAMENT.

M.S.C.P. OF TEST LAMP "B" = 203.1 x .79 = 160.44

DATA SHEET NO.3

M.S.C.P. OF LAMPS "C" "D" "A" IN TERMS OF LAMP "B".

LAMP	BOTTOM LAMP BURNING. SETTING ON M.V. WITH 1.604 SETTING ON S.M.P.	UPPER LAMP BURNING. S.M.P. READINGS WITH AVERAGE V.M. SETTINGS OF LAMP "B".		
	B	C	D	A
	98.0	169.8	85.0	70.3
	98.2	158.0	86.5	67.0
	98.6	165.0	86.0	69.7
	99.0	158.0	85.0	75.0
Av.	98.5	162.7	85.6	70.5
	98.2	158.0	83.5	71.0
	98.0	153.0	86.0	69.5
	98.0	155.0	85.0	73.0
	97.9	158.0	84.0	72.0
Av.	98.1	156.0	84.6	71.3
Av. of Av.	98.3	159.3	85.1	70.9

DATA SHEET NO.4

EFFICIENCIES AND LOSSES OF REFLECTORS R-6 AND R-5

	-----	R-6-C	R-6-D	R-6-A	------	R-5-C	R-5-D	R-5-A
	S	T	T	T	S	T	T	T
	97.0	147.0	68.5	57.0	96.0	156.0	73.0	62.0
	96.0	142.0	74.5	61.5	95.0	152.0	75.0	61.0
	96.0	142.0	76.0	60.0	94.9	152.0	71.0	60.5
	95.0	138.0	79.0	60.0	96.0	151.0	71.5	61.0
Av.	96.0	142.0	74.5	59.6	95.5	152.5	72.5	61.2
	96.1	149.0	78.0	56.0	93.0	144.0	75.0	69.5
	96.0	136.0	76.0	58.0	94.5	158.0	78.0	61.5
	96.3	146.0	73.0	53.0	93.0	159.0	70.0	63.0
	96.3	138.0	74.0	57.0	93.2	141.0	76.0	63.0
Av.	96.0	142.0	75.0	56.0	93.4	150.5	74.5	64.3
Av. of Av.	96.0	142.0	75.0	57.8	94.5	151.5	73.0	62.7
Losses	-	17.2	10.1	13.1	-	7.8	12.1	8.2
Eff.	-	89.0	88.0	81.6	-	95.2	85.7	88.5

DATA SHEET NO. 5

EFFICIENCIES AND LOSSES OF REFLECTORS R-4 AND R-3

	------	R-4-C	R-4-D	R-4-A	------	R-3-C	R-3-D	R-3-A
	S	T	T	T	S	T	T	T
	94.0	160.0	82.0	60.0	97.5	104.0	51.0	43.7
	95.0	153.0	83.0	64.0	97.6	105.0	52.7	43.0
	94.0	154.0	80.0	66.5	97.8	97.0	54.0	42.2
	95.6	160.0	82.5	62.0	97.2	102.0	54.5	41.2
Av.	94.6	158.0	82.0	63.0	97.5	103.0	54.9	42.6
	95.6	158.1	79.0	63.0	97.0	102.4	52.0	43.0
	95.2	158.3	84.0	61.5	97.0	100.0	51.0	42.8
	94.1	159.0	82.0	62.0	96.8	100.4	51.0	42.5
	95.1	160.0	84.0	62.0	97.0	98.0	50.5	43.8
Av.	95.0	158.8	82.0	62.1	97.0	100.2	51.5	43.0
Av. of Av.	94.8	158.4	82.0	62.5	97.3	101.6	53.2	42.8
Losses	-	.9-?	3.1	8.4	-	47.7	31.9	28.1
Eff.	-	99.5-?	96.4	88.4	-	63.8	62.5	60.5

DATA SHEET NO. 6

EFFICIENCIES AND LOSSES OF REFLECTORS R-2 R-10 R-9 R-8 AND R-7

	-------	R-2-D	R-2-A	R-10-D	R-10-C	R-9-A	R-9-D	R-8-D	R-7-A
	U	U	U	U	U	U	U	U	U
	97.0	58.0	49.0	69.0	130.0	55.0	68.0	75.0	58.0
	97.1	59.5	48.0	65.0	130.0	54.0	64.0	78.0	60.0
	97.2	58.0	48.0	64.0	125.0	59.0	67.0	72.0	64.0
	97.0	60.0	42.0	63.0	137.0	55.0	66.0	71.0	60.0
Av.	97.0	60.4	46.7	65.2	130.5	55.7	65.2	74.2	60.5
	96.3	59.0	49.0	63.0	125.0	53.0	62.0	71.5	52.0
	97.0	52.0	44.0	64.0	122.0	52.0	63.0	69.0	58.0
	96.5	59.5	44.5	63.0	125.0	54.0	67.0	75.0	59.0
	97.0	53.0	49.0	65.0	128.0	52.0	63.0	72.0	57.0
Av.	96.6	56.0	47.0	63.7	125.0	52.7	63.7	71.8	56.5
Av. of Av.	96.8	58.2	46.8	64.4	127.7	54.2	64.4	73.0	58.5
Losses	-	26.9	24.1	20.7	30.6	16.7	20.7	12.1	12.9
Eff.	-	68.4	66.1	75.7	80.5	76.5	75.7	86.0	82.5

DATA SHEET NO. 7

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SUMMARY SHEET

LAMP	I	E	RATING	WATTS INPUT	M.H.C.P.	M.S.C.P.	WATTS PER M.H.C.P.	LUMENS PER WATT
A	.88	110	100	96.9	89.55	70.5	1.08	9.15
B	2.25	110	250	247.5	203.1	160.4	1.22	8.15
C	2.28	110	250	250.8	-	159.3	-	8.00
D	1.25	110	150	137.5	-	85.1	-	7.8

DATA SHEET NO. 8